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PHOTOGRAPHY OF LUMINOUS EXTENDED OBJECTS AGAINST A TWILIGHT SKY

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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1. Introduction

Clouds of sodium, lithium, and potassium vapor are used to determine wind velocity and the coefficient of expansion for various heights in the upper atmosphere. These materials scatter sunlight radiation incident upon the cloud by a resonance process. The resulting scattered light is nearly monochromatic and is characteristic of the scattering atom. The vapor is released from a carrier-rocket during twilight periods at times when the cloud will be sunlit, but the background will be as low as possible.

To further increase contrast for optimum photographic registration of the cloud characteristics, filters and film types are used to augment as far as possible the ratio of light scattered by the cloud to background light Interference filters cannot be used effectively due to the wide angles over which the cloud extends.

A discussion of filter and film types for discrimination of the various wavelengths is given Developing techniques to insure the required contrast and photographic latitude are considered Film calibration and processing for subsequent densitometry is described Consideration is given to the changing background intensities encountered during twilight, and to the optimum exposure under these various conditions

2. Film and Filter Combinations

Sunlight scattered by the cloud is nearly monochromatic. The wavelengths of interest are:

1. Sodium 5890 and 5896 Å
2. Lithium 6708 Å
3. Potassium 7665 and 7688 Å

Filters are chosen which cut off the sky background to the short wavelength side of the desired resonance emission[1]. An appropriate film[2] is then selected which possesses the required contrast, is sufficiently sensitive at the desired wavelength, and which is insensitive to longer wavelength sky background. In the spectral region of interest for this work, it has not been possible to find filters which cut off light longer than a desired wavelength. Band pass filters of the colored gelatin type usually have prohibitively high attenuation at the wavelength of maximum transmission for the light levels available by resonance scattering. The maximum possible cloud surface brightness occurs for clouds or portions of a cloud which are optically dense. In this case the maximum brightness available is given by the solar flux times the scattering line width. A typical value of the solar flux is 3×10^3 photons/cm^2 · sec · Å, and a typical line width is 0.02Å. This leads to a surface brightness of 6×10^{11} photons/cm^2 · sec scattered into 2π steradians. Interference filters are generally not useful, since the cloud may cover 30 to 40 degrees in some of its dimensions as viewed from the photography sites.

Table 1 gives the spectral characteristics of various film and filter combinations which have been used or investigated for this work. All films listed are from Kodak (Rochester, N.Y.), and all filters are of the Wratten Series except the Corning 7-54.

TABLE 1

SPECTRAL CHARACTERISTICS OF REPRESENTATIVE FILM-FILTER COMBINATIONS

Film	Filter	Wavelength of Max. Sensitivity	Blue Half-Power Point	Red Half-Power Point	Equivalent Width
Spectroscopic I-O	7-54	3220 Å	3100* Å	3850 Å	750* Å
Spectroscopic I-J	12	5300	5170	5400	200
Spectroscopic I-G	15(G)	5650	5300	5720	415
Spectroscopic I-T	23A	5950	5765	6085	347
Tri-X (35, 70 mm type)**	23A	6000	5780	6310	535
Spectroscopic I-D	23A	6120	5810	6400	589
Royal-X Recording	23A	6280, 5950***	5805	6455	629
Spectroscopic I-F	29(F)	6755	6300	6960	610
High Speed Infrared	88A	8050	7500	8750	1200
High Speed Infrared	87	8200	7920	8750	800
High Speed Infrared	87C	8600	8380	8780	350
Spectroscopic I-N --	Similar Spectral Characteristics to High Speed Infrared				

* Estimate based on atmospheric transmission.

** Aerecon and sheet film Tri-X differ in their spectral characteristics from those given here for roll film.

*** Slight dip in sensitivity at 6100 Å.

3. Processing

To determine optimum conditions for photographic registration of the clouds produced, development times and formulas have been investigated. A criterion of maximum contrast without excessive fog and graininess has been used. Table 2 gives the results of this work In a majority of cases the optimum development times were found to coincide with the film manufacturer's recommendations.

TABLE 2

Film	Developer	Recommended Development Time at 68°F (20°C) (minutes)
Spectroscopic I-O, I-G, I-J, I-T, I-D, I-F	D-19	5
Spectroscopic I-N	D-19	4
Tri-X (35, 70 mm)	D-19	7
High Speed Infrared	D-19	8
Royal-X Recording	DK-50 or DK-60a	10 8

With these developers, the time at other temperatures is determined by increasing the time at 68° by 3%, 7% and 10% for 67°, 66° and 65° F., respectively, decreasing it 3%, 7% for 69°, 70°.

Development must be performed in total darkness for all the films listed with the exception of I-O with which a deep red safelight may be used if kept several feet from the film Agitation is continuous during the first 20 seconds to jar loose any air bubbles clinging to the film, then for 10 seconds once a minute, or the equivalent. Following development, the film is placed in a hardening stop bath compounded

of acetic acid and a saturated solution of sodium sulphate (Kodak SB-5), and agitated more or less continuously for two minutes. Use of this formula is recommended to keep swelling and movement of the image to a minimum[3]. Fixing films in an acid hardening fixing bath (sodium thiosulfate and Kodak Liquid Hardener, or in the prepared Kodak Acid Fixer) for three times the normally required time to clear (rather than the customary twice), followed by water rinse and treatment in a hypo elimination bath, and finally a washing in running water for 20 minutes guarantees a good measure of archival permanence in the films and dimensional stability in the images provided care is taken with regard to storage conditions, i.e., temperature between about 50 and 70°F., relative humidity 40 to 50%. Some difficulty was experienced at this laboratory with brittleness and flaking-off of emulsions before a humidifying procedure was adopted. It is especially important to store unexposed films at low temperatures in order to preserve their sensitivity and to forestall fogging. This is particularly necessary with infrared emulsions and high speed panchromatic materials such as Spectroscopic I-F, Royal-X Recording Film, etc., for which deep-freeze storage during as much of the time as possible is essential.

4. Absolute Sensitivity

Photographic density, D, is defined as the logarithm of the opacity, O, which in turn is the term given to the reciprocal of the transmission:

$$D = \log O = \log \frac{1}{T}$$

The response of a photographic material to light of various intensities is conveniently represented by a plot of density versus the logarithm of the exposure producing it, and known as the "characteristic", "Hurter and Driffield", or simply "D-log E", curve. Commonly, the curve has a toe region (in which the photochemical reactions in the photographic process can be thought of as being affected by inertia), an approximately linear region (the slope, γ , of this region is designated as the contrast), a curved shoulder portion in which the density approaches its blackest possible value, and a region of solarization, or reversal Many different methods for rating film sensitivity or "speed" have been used. They are based upon the shape of the H and D curve and its relative position along the exposure axis. Good accounts of the various methods are to be found in the literature of photographic theory[4,5,6]. In astronomical work it has been customary to base sensitivity upon the reciprocal of the exposure needed to produce density of 0 6 above chemical fog. In the new ASA standard method, a similar criterion has been adopted, with measurement being made, however, at the 0 1 level instead (Speed ratings in the latter system are less subject to influence by choice of developers, etc., than in most other systems)

Speed is always a function of exposure time, due to what is termed the "failure of the reciprocity law". In practice, the exposure producing a constant density in a photographic emulsion is proportional to $I \times t^p$, the product of intensity, I, times a power, p, of the time, t, rather than the simple product $I \times t$, which would be proportional to the energy falling on the emulsion. For the films listed in Tables 1 and 2, the Schwarzschild coefficient p can be taken as roughly 0.74 within a range of exposure times one-half to 15 seconds The effect of this phenomenon is to make most films slower for "time exposures" than for short "snapshot" exposures. Exceptions are the Kodak Spectroscopic emulsion Types 103a and IIa, which are specially made for heightened sensitivity to feeble illumination and hence have low reciprocity law failure and are of great value when top emulsion speed is wanted for exposures of anywhere from about 10 seconds to an hour or more. Such emulsions deteriorate especially rapidly unless stored at low temperature before use and prior to development.

The characteristic curves for a group of emulsions comprise Figure 1. Exposure was for six seconds to sodium D-line radiation. This exposure time and this wavelength are of major interest in the vapor cloud work. The curves can be adjusted for other times and wavelengths by recourse to the reciprocity and spectral sensitivity curves given by the manufacturer. Such data for the spectroscopic materials can be found in the Kodak booklet previously cited(2). Other curves can often be generously supplied by the Research Labs or the Special Sensitized Products Sales Division of Eastman Kodak It is always advisable to

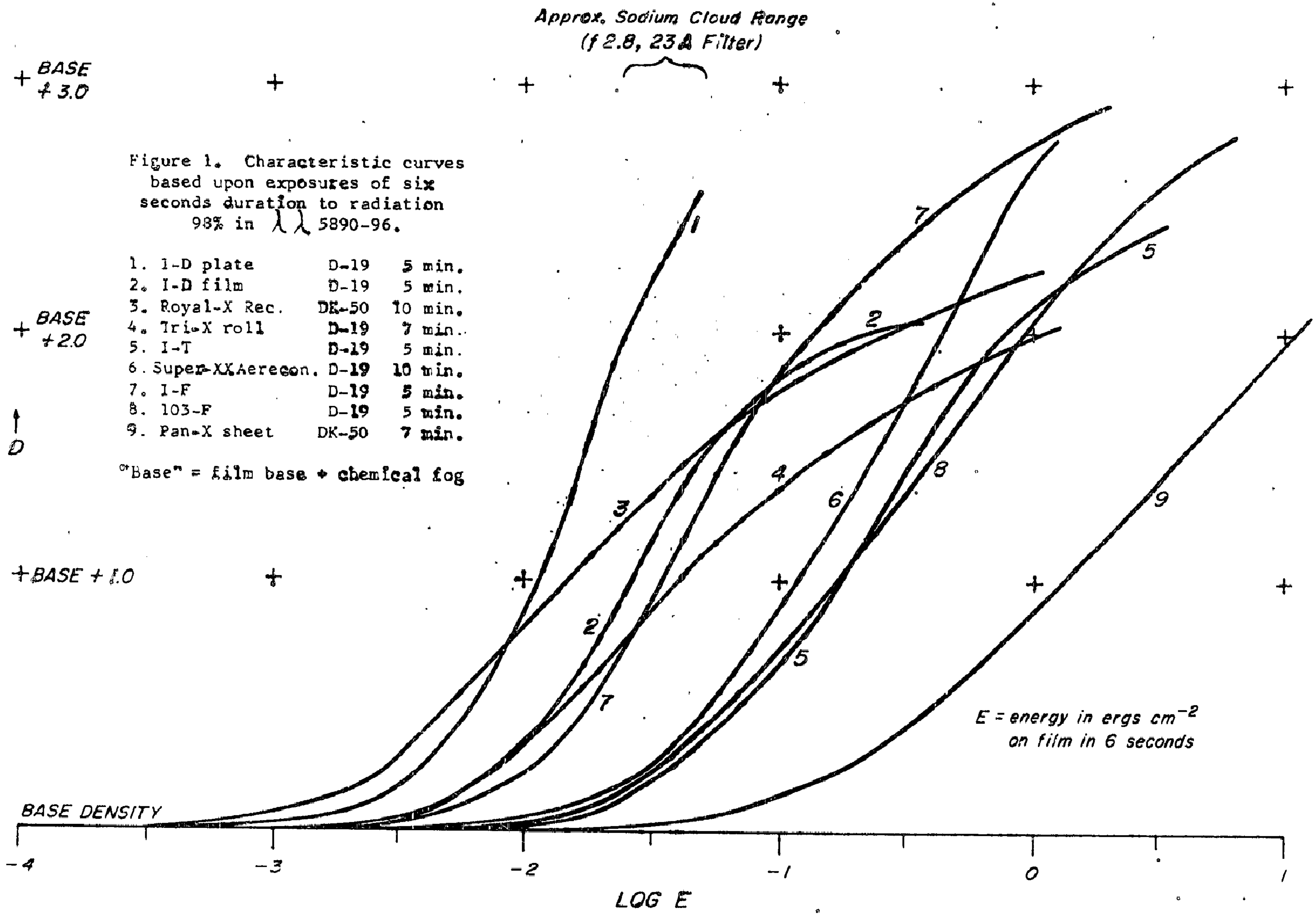


Figure 1. Characteristic curves based upon exposures of six seconds duration to radiation 98% in λλ 5890-96.

1.	I-D plate	D-19	5 min.
2.	I-D film	D-19	5 min.
3.	Royal-X Rec.	DK-50	10 min.
4.	Tri-X roll	D-19	7 min.
5.	I-T	D-19	5 min.
6.	Super-XX Aerecon.	D-19	10 min.
7.	I-F	D-19	5 min.
8.	103-F	D-19	5 min.
9.	Pan-X sheet	DK-50	7 min.

"Base" = film base + chemical fog

test or calibrate photographic emulsions under conditions as nearly as possible duplicating those of the actual application, especially where photometry is contemplated, insofar as photographic response is a function of many variables.

The exposures on which the curves in Figure 1 are based were made by placing a calibrated step scale nearly in contact with the emulsion and admitting light from a sodium lamp through a Packard 6R shutter, activated by a solenoid controlled by a Time-O-Lite Model P-59-4R timer box, of the type widely used in printing and enlarging work. Thus the exposure time could be precisely chosen and rendered repeatable. Illumination intensity was controlled by adjusting the voltage to the lamp to give a constant reading on a microammeter connected to a selenium photocell (International A15-M). The films and plates were developed as specified and were densitometered on a Jarrell-Ash 23-100 Recording Microphotometer.

For the absolute zero-point of the energy-scale (energy incident on the emulsion per unit area during an exposure of specified duration), a weighted mean was obtained from Kodak data, comparison source candle-power estimates (using L.E. Barbrow's[7] method), data from two papers by R. Clark Jones[8], and solar energy--sodium lamp intercomparisons (using D-line interference filters, neutral densities, and a photocell) The zero-point relative to the average position of several curves is estimated to be valid to $\pm$ 0.06 $\log_{10}$ units (p.e.), though the accuracy of a point on an individual curve should probably be taken to be somewhat

lower, because of the many variables affecting repetition of results. Among the ones not previously mentioned: (a). temperature of the emulsion at time of exposure (see Selwyn[4], pp. 58-59, and Evans[9], and (b) changes in the shape of the H and D curve between exposure and development. There is some indication of a gain in speed occurring for low densities at a rate roughly proportional to the logarithm of the storage time after exposure, with certain emulsions[10]. With long storage times, the gain may amount to as much as a doubling of speed[11], but fog build-up must also be reckoned with.

5. Exposure Determination

If film is developed for contrast, and highest effective speed possible without a major sacrifice in image quality, as is the case with all the examples given in Table 2, the exposure latitude is small. It is necessary to expose correctly within one or two f-stops, which is to say, within a factor of about 3. By experience, the best exposures under twilight conditions are found to be those which place sky background level at photographic density 0.2-0.4 above chemical fog*. Then the cloud photographs are on the straight-line portion of the H and D curve. In consequence, faint detail often registers that would otherwise be invisible, and also there is provided a margin of safety against underexposure. Unless the cloud is extremely bright, overexposure will not result; if the bright highlights are more important than the fainter portions of the cloud, less exposure should be given. If, on the other hand, detail of both varieties are to appear on the same negative, less development or a less contrasting emulsion must be used (such as by substituting Type 103 for Type I). It is still desirable, however, to place the background at 0.2 to 0.4. The exposure recommendations given are based upon the assumption that faint detail is desired**.

*In general, aiming for a background density on the high side, say 0.4, in the center of the field, will insure somewhat against loss of sensitivity toward the edges of the field due to the decreased film-plane illumination off-axis.

**The amount of exposure for optimum contrast of faint detail, obtained by placing sky background density in the range 0.2-0.4 is quite consistent with recommendations for pre-exposure given by Branscomb(12), Green(13) and others cited by Branscomb. In effect, the twilight sky background "pre-exposes" the film for maximum sensitivity.

To fulfill the above conditions towards the night side of twilight, maximum lens apertures and the fastest films are required. When the sky is brighter, e.g., at solar depression angle d $\leq 5^{\circ}$, a choice of (a) smaller lens openings, (b) shorter exposures, or (c) slower emulsions is available. At such times the equivalent width of a film-filter combination is a more important consideration than the film's sensitivity. A "narrow" combination such as I-T emulsion with 23A filter, for sodium 5890Å, will give better cloud contrast than a faster, though broader, combination such as Royal-X Recording Film with 23A filter, for which less exposure can be given. The lens opening (f-stop setting), exposure time, or film type may be considered as principal variables, one or two of which may be held constant. Another consideration is graininess. Where grain quality and resolving power are of importance, slower films should be used and exposure increased correspondingly.

Tables 3 and 4 show f-number versus solar depression angle d for various film and filter combinations with development as recommended in Table 2. They are intended as a rough guide, and tests should be made where possible prior to actual application over a range of $\pm$ 2 f-stops. Tables 3 and 4 have been prepared as a guide for the operations at Wallops Island. The depression angles referred to are local, i.e., computed for the individual observer's position. To use the tables, the solar depression angles must be converted into Standard Times for the particular date and place of application. These tables are based upon the brightness of the zenith. The twilight sky is generally brighter

TABLE 3

LOCAL SOLAR DEPRESSION ANGLE VERSUS f-NUMBER AND EXPOSURE TIME FOR PROPER REGISTRATION OF ZENITH SKY BACKGROUND WITH CERTAIN FILM-FILTER COMBINATIONS: TRIAL VALUES

See Tables 1 and 2 and text for spectral characteristics and processing requirements.

Representative f-Number-Exposure Time Combinations	Film:	I-O	I-T	Tri-X 70 mm	I-D (film)	Royal-X Recording	I-F	Hi-speed Infrared	I-N
	Filter.	7-54	23A	23A	23A	23A	29(F)	88A	88A
f2 - 12 sec, f2.8 - 30 sec,etc.		7.5°	7.9°	7.9°	8.0°	8.6°	7.7°	8.4°	7.6°
f2-5 sec, f2.8-12 sec, etc.		7.1	6.5	7.4	7.5	8.1	7.2	7.9	7.1
f2-2 sec, f2.8-5 sec, etc.		6.8	6.1	7.0	7.1	7.7	6.8	7.5	6.7
f2-1 sec, f2.8-2 sec, etc.		6.4	5.7	6.6	6.7	7.3	6.5	7.1	6.3
f2.8 - 1 sec., etc.		6.1	5.3	6.2	6.2	6.8	6.0	6.7	5.9
f4 - 1 sec, etc.		5.7	4.9	5.8	5.8	6.4	5.6	6.3	5.5
f5.6 - 1 sec, etc.		5.3	4.1	5.4	5.4	6.0	5.2	5.9	5.1
f8 - 1 sec, etc.		4.8	(3.0)	4.9	5.0	5.6	4.3	5.5	4.3
f11 - 1 sec, etc.		4.0		4.1	4.2	5.1		5.1	
f16 - 1 sec, etc.						4.3		4.3	

TABLE 4

LOCAL SOLAR DEPRESSION ANGLE VERSUS f-NUMBER WITH 6-SECOND EXPOSURES FOR PROPER REGISTRATION OF ZENITH SKY BACKGROUND WITH CERTAIN FILM-FILTER COMBINATIONS: TRIAL VALUES

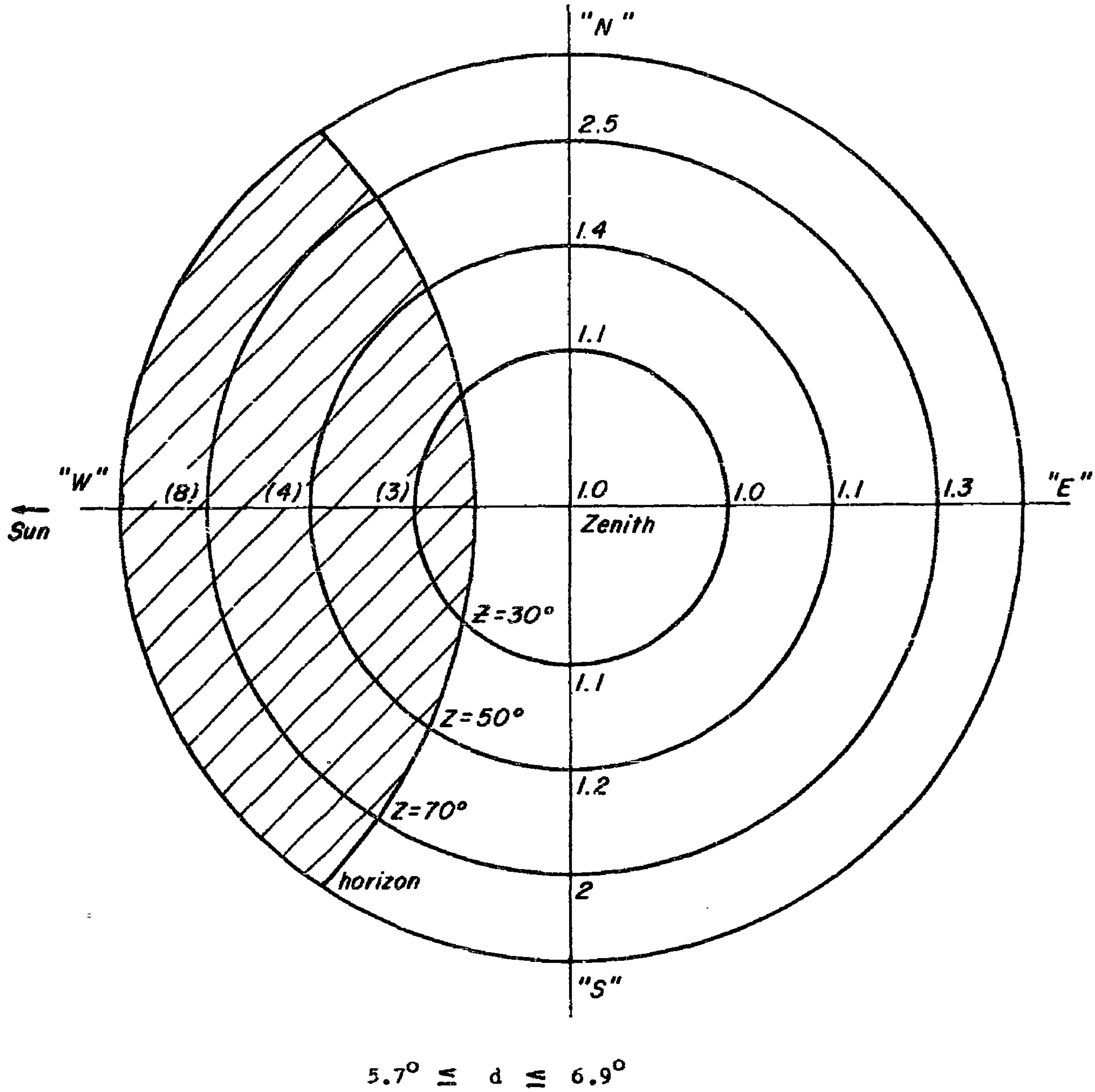
See Tables 1 and 2 and text for spectral characteristics and processing requirements.

f-Number for 6 Seconds' Exposure	Film: Filter:	I-O 7-54	I-T 23A	Tri-X 70 mm 23A	I-D (Film) 23A	Royal-X Recording 23A	I-F 29(F)	Hi-speed Infrared 88A	I-N 88A
f2		7.7°	6.5°	7.5°	7.5°	8.1°	7.2°	7.9°	7.1°
2.8		7.4	6.1	7.0	7.0	7.7	6.8	7.5	6.7
4		7.0	5.6	6.6	6.6	7.3	6.4	7.1	6.3
5.6		6.6	5.2	6.2	6.2	6.8	6.0	6.6	5.8
8		6.3	4.7	5.8	5.8	6.4	5.5	6.2	5.4
11		5.9	(3.9)	5.3	5.3	6.0	5.1	5.8	5.0
16		5.6		4.9	4.9	5.6		5.4	

in directions other than the zenith, markedly so towards the direction in which the sun is about to rise or has just set. Empirical ratios have been determined to relate the intensity over various parts of the sky to zenith intensity. Some typical ratios are illustrated in Figure 2, and others can be found by estimation or photometry. A curve useful for predicting zenith brightness as a function of depression angle is included in Figure 3.

Diaphragm changes from one f-stop to the next should be accomplished approximately midway between the times corresponding to the values of depression angle listed in Tables 3 and 4 for those f-stops, or the diaphragm might be adjusted continuously by automatic means. Net uncertainty in the table is estimated to be of the order of $\pm$ one f-stop, under normal circumstances, in the range 4° to 10° local solar depression angle, making advance tests advisable. In practice, at least some cameras at each site have utilized a sequence containing one 3-sec, one 6-sec and one 12-sec exposure each 30 sec. This assures that a proper exposure is available for bright and faint portions of the cloud. When higher time resolution (more rapid frame rate) is required, a single exposure time is selected. Fast film and short exposure times best satisfy this condition. In this case, a rather precise determination of the exposure must be made.

FIGURE 2. TWILIGHT SKY BRIGHTNESS DISTRIBUTION MEASURED ON A TYPICAL EVENING. "WEST" IS THE AZIMUTH OF THE SUN.



$5.7^{\circ} \leq d \leq 6.9^{\circ}$

I-D film, 23A filter } $\lambda_{max} = 6120$ Å

Evening of 30 January 1961, Bedford, Massachusetts

The ratios in the shaded portion are changing especially rapidly in the interval $4^{\circ} \leq d \leq 7^{\circ}$ and accordingly are given in parentheses.

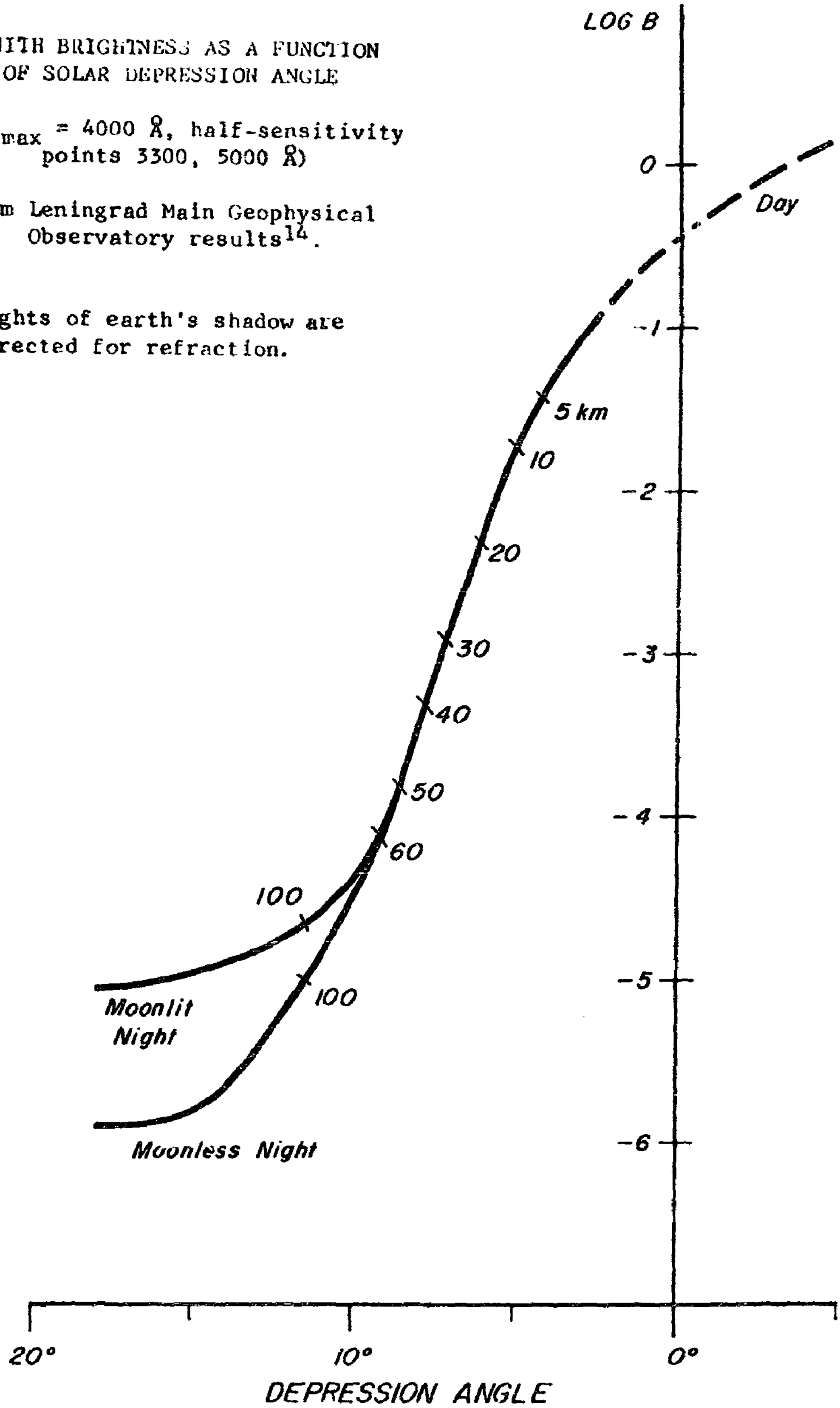
FIGURE 3.

ZENITH BRIGHTNESS AS A FUNCTION OF SOLAR DEPRESSION ANGLE

(λ_{max} = 4000 Å, half-sensitivity points 3300, 5000 Å)

from Leningrad Main Geophysical Observatory results[14].

Heights of earth's shadow are corrected for refraction.



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